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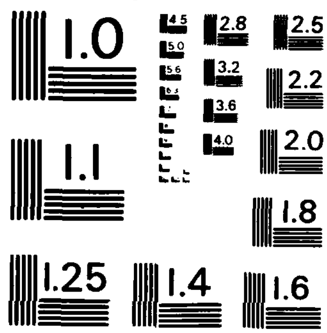

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Professional Paper 442 / October 1985

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Price Analysis and the Effects of Competition

by

R. Berg
R. Dennis
J. Jondrow

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A Division of CNA Hudson Institute

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INTRODUCTION

This paper reports on the literature review portion of an ongoing study of competition in defense procurement. The literature under consideration is drawn from two sources: papers written under contract for various agencies within the Department of Defense and papers written by Defense Department employees. These papers are retrospective evaluations of the effects of competition on the costs of weapons programs already completed.

The remainder of this paper is divided into three parts. The first part will present the commonly accepted model used to evaluate competition. The second part will discuss the data and results presented in the literature. The final section of the paper will present some tentative conclusions on the adequacy of the model as both a retrospective and prospective tool for analyzing the effects of competition.

THE BASIC MODEL

Most analyses of the effects of competition focus on how competition will change the costs directly related to production. These costs are called recurring costs and include items such as materials and manufacturing labor. From the government's point of view the recurring cost, as used in competition analysis, is the unit price the government pays for a weapon system. The focus on unit price arises from the fact that competitive savings, if they exist, result from reductions in unit prices over the life of the system.

Virtually all of the unit price models that have been used to analyze the effects of competition are based on the learning curve paradigm. The original learning curve arose from the observation that the number of manhours required to produce an airframe fell with an increase in the number of airframes. Figure 1 illustrates this observed relationship in its simplest form.[1] The labor learning effect illustrated in figure 1 was generalized to all inputs and subsequently to unit production costs.

The procurement literature tends to push the generalization of the learning effect a step further by assuming (implicitly) that the effects of learning are pervasive and that any cost reductions are passed through directly to prices. Given this implicit assumption, the learning curve

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1. In the case of airframes the simplest form of the learning curve is given by hours/lb = $T_1 Q^a$. Where hours/lb represents the manhours required per pound of airframe required to produce the Qth airframe, T_1 represents the manhours required to produce the first airframe, Q is the cumulative airframe number, and a is the learning parameter.

is transformed into a price improvement curve (PIC).[1] The price improvement curve may take any one of several forms:

- A simple PIC in which cumulative quantity is the only right-hand-side variable
- A rate-adjusted PIC that includes a production rate variable
- Some other form of adjustment to the simple model (see [16] for an example using industry capacity utilization as a variable).

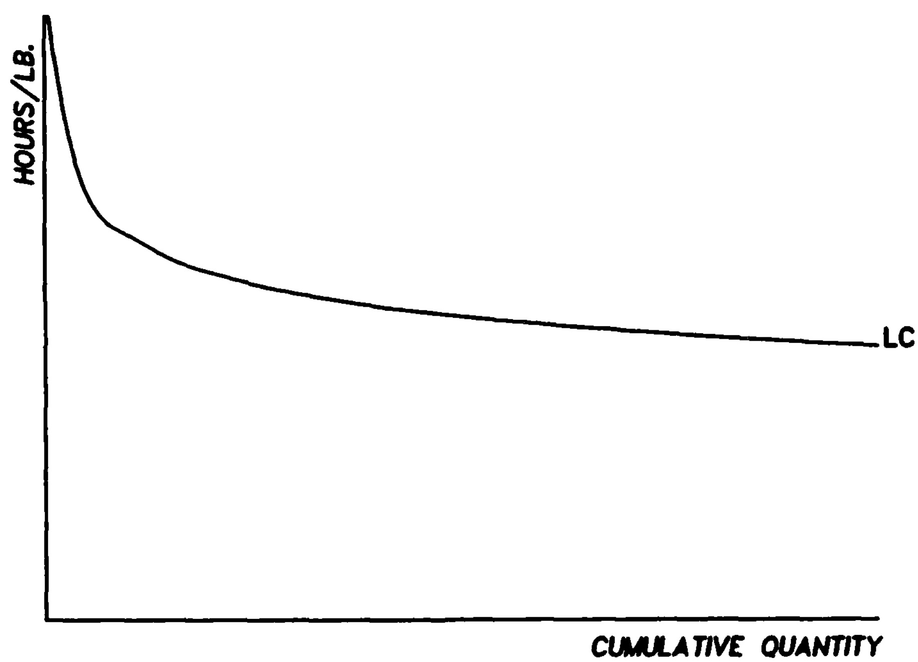

FIG 1: THE LEARNING CURVE

1. The dominance of this concept is evident in the fact that references [2, 3, 4, 5, 8, 9, 10, 12, 13, 16, 17, 20] all use a learning curve or PIC-based approach. Of the remaining references only [1] is directly concerned with estimating the effects of competition on procurement costs.

The log-log form of the simple price improvement curve is illustrated in figure 2. The key feature of the simple curve is that the price paid for the weapon system falls as the total number of systems produced increases. The steeper the curve, the faster the price drops.

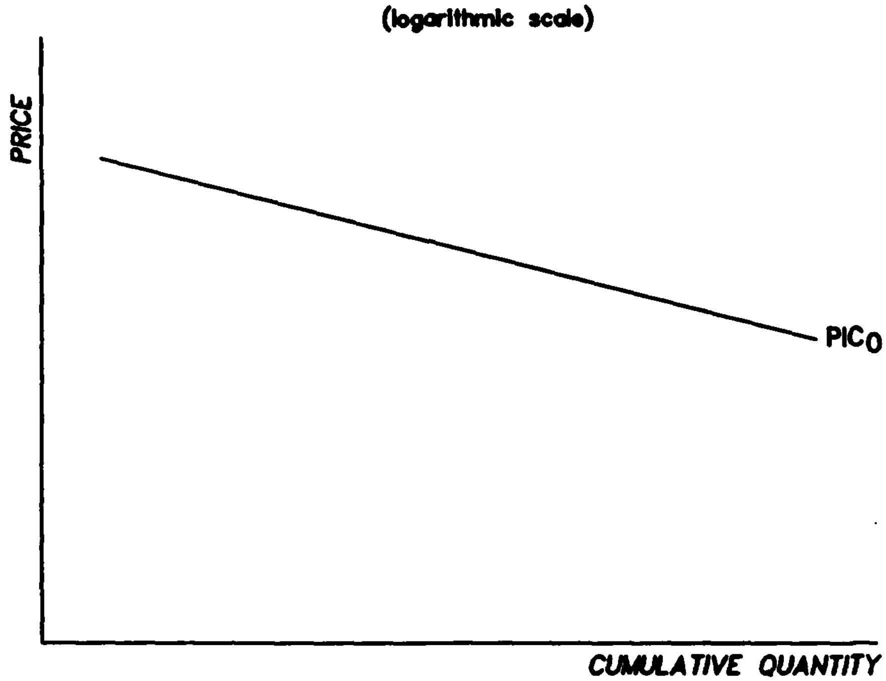

FIG. 2: THE PRICE IMPROVEMENT CURVE

The key concept of the pricing models is the assumed pass-through of learning effects to prices. However, many studies also recognize the potential effects of the rate of production on costs and include this consideration in their models. Since higher production rates are usually assumed to reduce unit costs, splitting production between two competing producers in dual-source acquisition programs may actually lead to higher unit prices. Figure 3 illustrates two price improvement curves for two different production rates. Note that PIC_0 corresponds to a lower production rate than PIC_1.

Given the basic PIC model of price formation, the effects of competition are generally represented as: a shift in the PIC, a rotation in the PIC, or both. The composite hypothesis that both a shift and rotation occur in response to competition is illustrated in figure 4. Figure 4 illustrates the particular hypothesis that the introduction of competition lowers prices to the government.

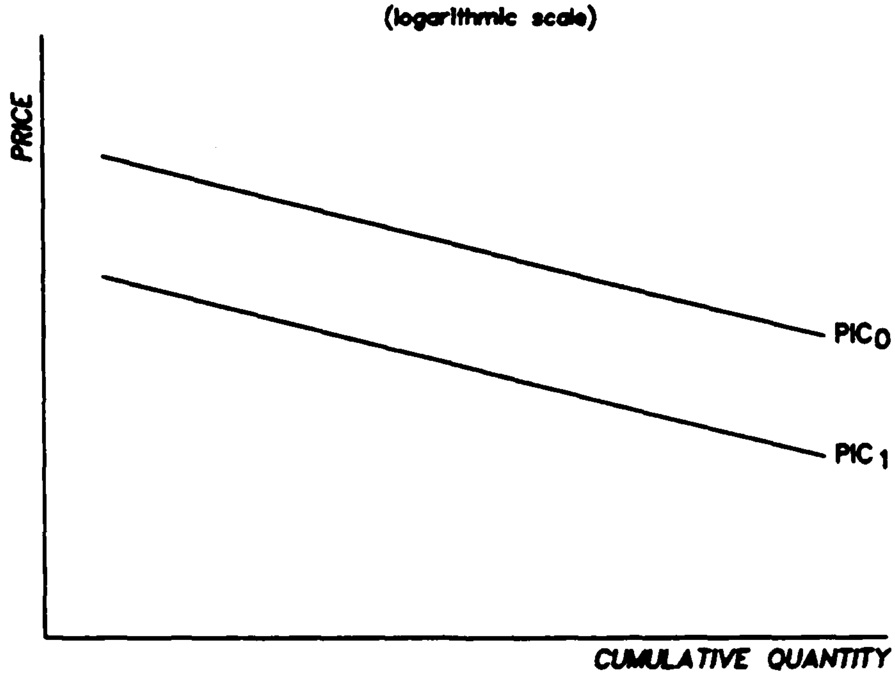

FIG. 3: THE EFFECT OF RATE ON THE PIC

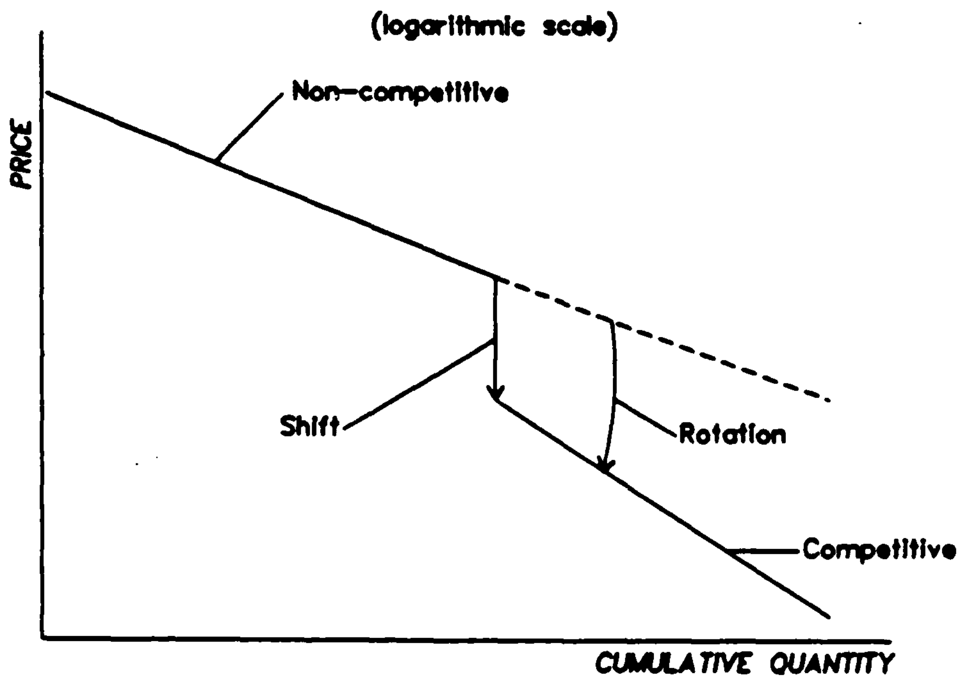

FIG. 4: THE EFFECT OF COMPETITION ON THE ORIGINAL SOURCE

Figure 5 illustrates the basic technique used in the literature for computing the recurring savings from competition. The analyses of competition in the literature are retrospective, not prospective. Consequently, there are several factors to keep in mind in examining this technique and the associated results: (1) analyses are program specific, (2) knowledge of the sole-source history prior to the introduction of competition is necessary, (3) the PIC is assumed to accurately represent the pricing decisions of firms, and (4) shift and/or rotation in response to competition is expected and is a maintained hypothesis. Estimates of recurring savings are developed in the following way:

1. Price behavior that occurred prior to the introduction of competition is used to estimate a sole-source price improvement curve.

2. The resulting parameter estimates of the PIC are then used to estimate what prices would have been in the absence of competition. The estimate is illustrated by the dashed line in figure 5.

3. These estimated sole-source prices are then compared to the average price of the corresponding lot procured under competition. The savings per unit is the difference between the sole-source price and the average price of the competitive lot.

4. The lot savings are computed as the product of the savings per unit and the total number of units in the lot.

Given the estimated savings for each lot, the procedure for calculating total program savings varies depending on the availability of other data and on the attitude of the researcher. If nonrecurring costs are not available, then the sum of the individual lot savings may be presented as the estimate of gross savings. If nonrecurring costs are available, then the researcher must decide whether to discount the savings to account for the time value of money and what discount rate to use. In either case the result will be presented as net savings.

In some of the cases reviewed, this procedure was modified because there were insufficient sole-source data to estimate a pre-competition PIC. As a consequence, a price improvement parameter or production rate parameter was assumed by the researcher(s). Given the sensitivity of the savings estimates to parameter values, the estimates of competitive savings based on assumed parameter values must be viewed as having a greater degree of uncertainty than would be the case if all parameters could be estimated from available data.

The discussion above has presented the basic theoretical model and the empirical approach used in the literature to evaluate the effects of competition. The next section will consider the application of these theoretical and empirical models. Of particular interest are the results

reported in the literature on competition and the applicability of the data bases used.

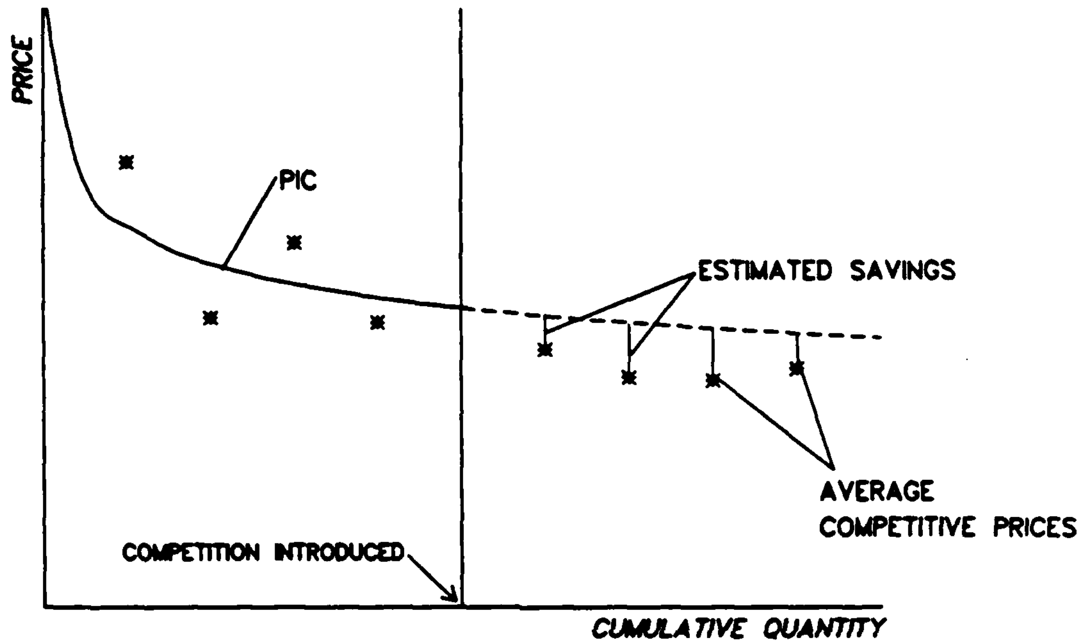

FIG 5: THE PIC AND ESTIMATED SAVINGS

THE DATA BASE

Cases

The studies reviewed were based on a total of 61 programs. There were 31 electronic subsystems or components programs, 18 missile or missile parts programs, 7 bomb or munitions programs, and 5 torpedo programs. Each study covered several programs, but no single study covered all the programs. Almost all of the studies took a case-by-case approach, considering one program at a time and without any attempt to draw insights from other programs.

The majority of the programs (36) had used the winner-take-all competitive method, where the entire production quantity is awarded to the winner. Fourteen programs divided the production between two or more competitors in what are called dual-source or split buys. Four programs were sole-source procurements. The procurement methods for seven programs were not identified.

Selectivity Bias

Several aspects of the cases used in this literature suggest the possibility of selectivity bias, that is, the cases may be atypical of what can be expected from competition in the future, particularly the results on cost savings.

- The standard PIC methodology for estimating competitive cost savings in this literature can use only cases that are sole-source initially followed by competition. Thus, production programs that were competitive from the outset were excluded.

- The fact that the cases were sole source at the outset, followed by competition, raises the possibility that some of the competitions may have been used as a means of solving problems with sole-source programs. A sole-source program with problems may have been a high-cost program as well.

- Over half of the cases reviewed were electronic components and subsystems. Electronic components are usually part of a weapon system and, therefore, are inherently less complex than the entire system. Also, electronic components may be more like commercial products than are weapon systems themselves. For these reasons, there may be more qualified competitors, and thus more effective competition and greater savings, for components production than for system production.

- Over half of the cases reviewed were winner-take-all competition. All cases in this literature occurred before the recent emphasis on split-buy competition during production. The driving reason for split-buy competition during that era may not have been expected cost savings. The recent literature has discussed the hypothesis that winner-take-all competition yields greater savings than split-buy competition [5, 10, 11, 17]. Beltramo [17, pp. 79, 82, 109], in reviewing 7 split buys and 18 winner take-all competitions makes the following conclusion about this era: "Thus, all types of competition do not produce the same results: Winner-take-all competitions usually result in savings; split-buy competitions often increase costs."

THE SAMPLES

The previous section discussed the general characteristics of the data base on competition. A more specific discussion of sample characteristics is necessary before turning to the results reported in the literature.

Figure 6 shows the data from the AGM-12B missile program for the original producer, Martin. The most important factor to recognize in this diagram is the paucity of data. There are only three data points

before competition began and six after. The AGM-12B program is typical in this respect.

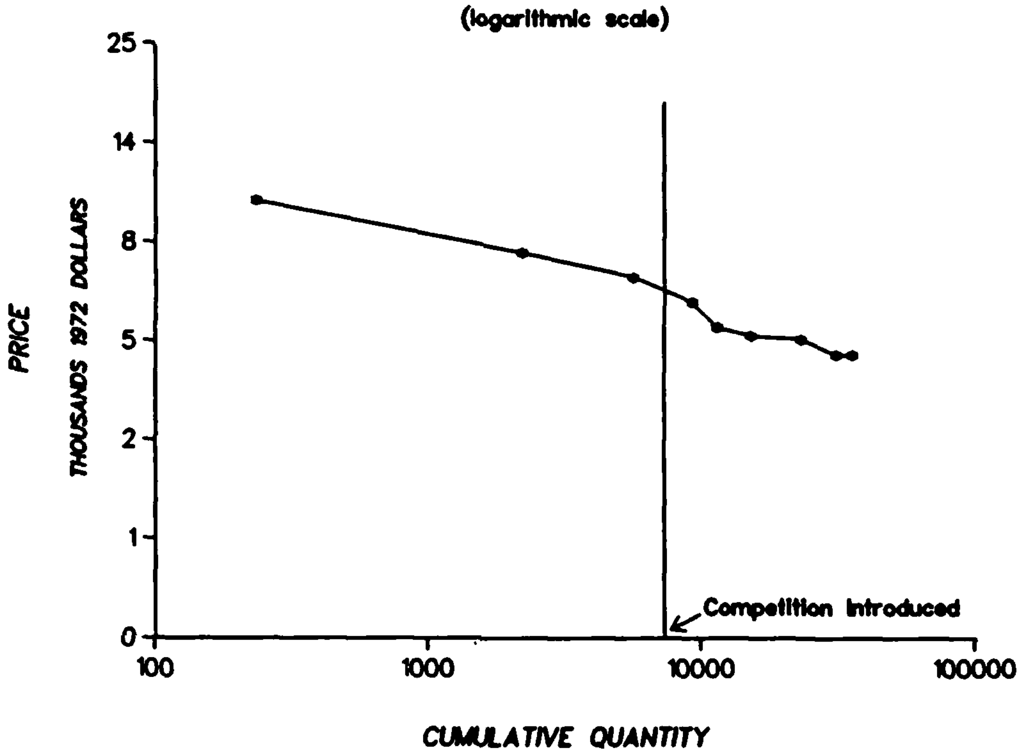

FIG. 6: PRICE IMPROVEMENT CURVE FOR THE AGM-12B MISSILE MANUFACTURED BY MARTIN

Small samples make statistical estimation difficult, and the resulting estimates have large variances. The AGM-12B program is a case in point. Although Martin appears to have changed pricing behavior after competition was introduced, the data fail to show statistically significant differences. In this instance, the availability of only three data points before competition began did not provide sufficient information for comparison to the competitive situation.

Given the characteristics of the data base and samples, the next section considers the effects of competition as reported in the literature.

RESULTS

Figure 7 illustrates the variation in results by program and by study. A subset of the 61 programs was selected for which there were at least three estimates of cost savings among the five references listed in the figure. Plotted on the vertical axis are estimated percentage savings. The horizontal axis lists the selected programs. The variation of savings from program to program is apparent in scanning the horizontal dimension.

The study-to-study variation of estimated savings for any given program (shown by variation in the vertical dimension in figure 7) suggests that the details of the calculations can have a large effect.

The best example of the study-to-study variation for a single program is seen in the AIM-7F program, which is too recent to have been included in the studies from which figure 7 was drawn. The different estimates of savings for the AIM-7F are given in table 1.

An SAI study in August 1982 [9] estimated that competition actually resulted in a 20.5 percent increase in costs, or a negative savings as shown in table 1. When the study was updated for publication in September 1982 [10], the extra costs of the directed or educational buy were taken into account, increasing the costs or negative savings to over 30 percent. Then another assumption was changed. The prospect of competition was assumed to have steepened the learning curve, even before competition started [12]. When that assumption was incorporated in the analysis, the estimated savings went from about -30 percent to about +11 percent. So within these three studies, all by the same authors, there was a variation of about 40 percent, depending on assumptions.

There are a number of other reasons for variation in estimated savings from study to study such as differences in data, differences in ways of correcting for inflation, the presence or absence of discounting, differences in the percent of the program completed when estimates were made, whether the effect of production rate on price is considered, and differences in estimating equations.

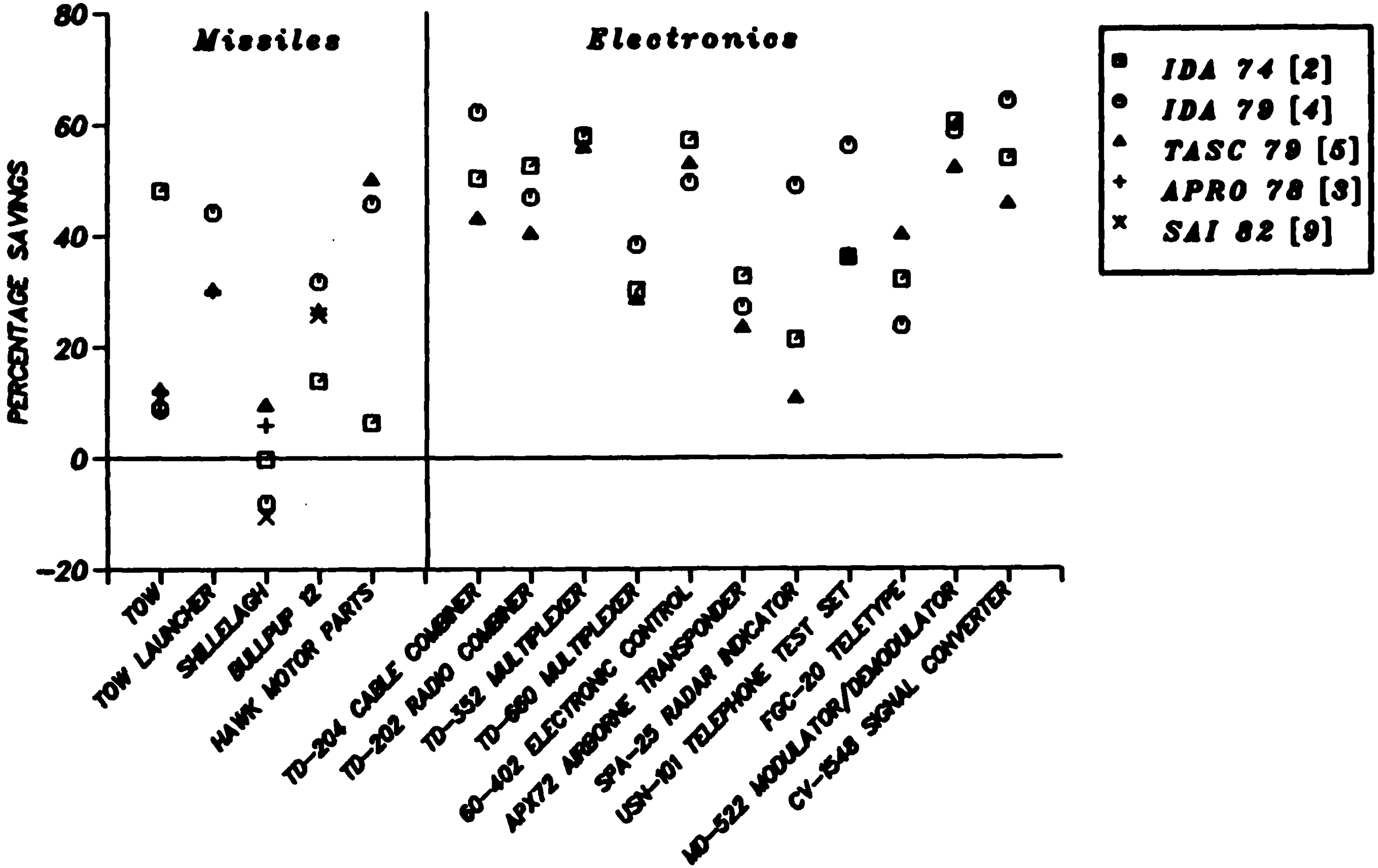

FIG. 7: ESTIMATED SAVINGS FOR DIFFERENT PROGRAMS AND DIFFERENT STUDIES

TABLE 1

ESTIMATED SAVINGS FOR AIM-7F

Source	Estimated savings
SAI (August 1982)[a]	-20.5%
SAI (September 1982)[b] Effect of educational or directed buy	-30.4%
SAI (March 1983)[c] Effect of competition on slope of sole-source "learning curve"	+11.0%

a. [9].
b. [10].
c. [12].

Variables

The variables used to analyze competition have tended to be limited to those needed for a learning curve: inflation-adjusted price, cumulative quantity, and production rate. Other promising variables that rarely appear in the literature could affect the results significantly. For example, product characteristics (such as weight, speed, and complexity for a missile or airframe) are important in standardizing price so that comparisons can be made across programs. Economic variables also are important because they have a direct impact on the effect of competition. They include market structure (how many other firms can produce this type of product?), capacity utilization (the actual level of production relative to potential level), expectation of competition (did the prospect of competition have an effect before it was actually introduced?), and prices of earlier versions (was profit being made on previous buys or previous versions?).

These additional variables have cross-sectional variation as well as time-series variation--that is, they vary across different items as well as over time. The studies reviewed almost exclusively used a time-series approach in which data for one program over time were analyzed in isolation. The introduction of other variables would be a step toward adding a cross-sectional perspective to the analysis.

Screening Criteria

The literature includes numerous discussions of screening criteria--to suggest which programs were the most promising candidates for competition. Even though a number of criteria are identified (such as the expected rate of production, the stability of the production plans, whether special production skills are needed and whether the sole source is "inefficient"), most were not quantified or tested. Considerable research remains before screening criteria can be used with reasonable confidence.

Coverage of Issues in the Literature

The issues covered in the literature focus narrowly on the learning-curve methodology. As a consequence, a number of possibly important issues are not considered. Was the low price bidder able to perform? What was the claims experience on these programs? How much competition was there before formal competition started? For instance, did the research and development process incorporate competition in the sense that companies may have bid low for the research and development in hopes of making money on the production?

Another problem, noted earlier, is that the literature has failed to distinguish between price and cost, and between the level of price and the change in price. A program whose price is falling rapidly is considered to be efficient, without consideration of the possibility that the reason for the rapid fall in price may be that the price started off very high. A falling price does not necessarily mean that either the final price is low or the program is efficient.

A final issue is the long-run state of the market. For instance, is it possible that competition can squeeze a company to greater efficiency or lower profits in the short run, but force it out of business in the long run?

ASSESSMENTS AND CONCLUSIONS

The principal conclusion to be drawn from this examination of the literature is that the PIC model, in either its simple or rate-adjusted form, is inadequate for analyzing pricing behavior under competition. The problems with the PIC exist on both the theoretical and empirical levels.

Theoretical Issues

Models of economic phenomena are typically built from a consideration of the behavioral, institutional, and technical characteristics of the problem. If an economic model of defense procurement prices is to contribute to an understanding of the effects of competition in weapons system acquisition, it should consider these three broad characteristics.

The typical PIC-based approach considers only production quantity and production rate and thus suffers from incomplete specification.

Behavioral

The behavioral characteristics in economic models are essentially contained in descriptions of behavior derived from the assumed goals of the decision-maker. Qualitative examples of the behavioral aspects are found in statements such as "The quantity of a good that consumers will purchase decreases as the price of the good increases," or "The amount that a firm wishes to sell increases with the price of the good." It is important to recognize that these statements are conditional upon assumptions. For example, in the economic theory of consumer behavior, the typical consumer is assumed to prefer more of a good to less and to have a limited income.

The importance of the behavioral considerations is that the predictions of the consumers' or producers' actions are conditional upon the existence of an assumed set of goals and constraints. The PIC approach to pricing in general, and competition in particular, fails to define the elements that would lead to the hypothesized behavior.

Of the papers reviewed in this study, only Greer and Liao [16] and Beltramo [17] discuss the behavioral aspects of the procurement process. Greer and Liao approach the behavioral aspect by citing three alternative strategies a firm may choose in response to competition:

1. Constant percentage profit--price is a constant percentage markup over cost.

2. Penetration (limit) pricing--if the government has not committed to competition, the firm sets a price that is low enough to discourage the introduction of competition.[1]

3. Skimming pricing--if the government has committed itself to competition, the firm sets a high price and lowers it as necessary to meet competition.

Greer and Liao never follow up explicitly on these alternatives. However, their empirical work does include a measure of industry capacity utilization that reflects some consideration of the behavioral alternatives available to a firm.

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1. If a contractor knows the government's criteria for introducing competition, the limit price can be calculated and the profitability of this approach compared to other pricing strategies.

Beltramo [17] notes that a variety of economic models can be used to describe the behavior of a firm and that the particular model depends upon the situation. Beltramo suggests that the approach found in the Stackelberg duopoly model might be appropriate for dealing with dual-source competition.

The Stackelberg model recognizes two types of firm behavior. A firm may choose to be a leader and pursue a dominant market position by using aggressive strategies in areas such as price and quality. Alternatively, the firm may choose to be a follower and adopt a set of passive strategies in areas of potential competition. In this instance, the follower firm will serve that segment of the market that the leader firm cannot supply, possibly ending up with a small, but profitable, market niche. Beltramo [17, p. 41] observes, "...competition will be assured only when both firms seek to become the leader, as both will then seek to capture a larger share of the market by bidding down the price."

While Beltramo's discussion is an excellent beginning toward development of a complete model of pricing behavior, it does not explore the determinants of pricing strategy and the implications for empirical models. Ultimately, Beltramo relies on the PIC formulation for empirical work.

Institutional

Institutional characteristics of a situation would typically include such factors as the law and the internal structure and rules of the decision-making organizations. Since the institutional characteristics typically manifest themselves as constraints on the decision-makers, a general rule is that the more stable the institutional environment the less important the institutions are in explaining the behavior.

The PIC approach is based on data drawn from an environment in which competition occurred at the concept design or demonstration and validation stage of the procurement cycle. The introduction of competition during production as the baseline approach to procurement represents a major change in the way DOD and the Navy do business. If firms change the way they price their products, which should be expected since firm pricing decisions are based upon the business environment in which the firm operates, then the simplistic PIC approach will fail to provide an adequate base for analysis.

A prime example of this structural change phenomenon can be drawn from the economics literature. From the late 1950s until the mid-1970s the Phillips Curve was one of the main conceptual and empirical tools for macroeconomic policy-makering. The Phillips Curve was based on the observation that high rates of inflation and high rates of unemployment had never occurred simultaneously. Consequently, by following an inflationary policy, government could keep unemployment low. In 1975, however, the inflation rate and unemployment rate both hovered around

7 percent, which, according to the Phillips Curve, was an impossible combination. Subsequent research showed that the supposed tradeoff was only valid for random variations of inflation around a stable mean, and that the advent of systematic year-to-year increases in the inflation rate changed the relationship substantially.

The acquisition community is likely to experience considerable difficulty in evaluating prices in general, and the effects of competition in particular, during the transition to the new way of doing business. This difficulty is likely to persist until the procurement environment stabilizes and both the firms and the government are able to sort out the information and determine the appropriate rules of behavior.

Technical

The PIC model as found in the literature is essentially a cost-based model of price. However, the only technical factors included are the production rate and the cumulative quantity. The exclusion of other relevant variables, such as resource prices and system characteristics, suggests that the PIC is an incomplete model of prices. This conclusion is reinforced by the universal failure of the literature to explain how the firms transform their costs into price offers.

Consequences of Incomplete Specification

The incomplete specification of pricing behavior causes two specific problems:

- First, the failure of the literature to consider a number of factors that are recognized as important at other levels of analysis implies a fundamental conceptual incompleteness in the treatment of both price formation in general and competition in particular. The danger is that the simple model will result in simple and inappropriate solutions to a complex problem.

- Second, the exclusion of important variables from the analysis implies that the empirical effects of competition on prices may be estimated with systematic, but unknown, errors. This statistical problem compounds the conceptual problem cited above.

Alternative Hypothesis

The discussion above concentrated on general problems associated with the PIC approach to price analysis and the potential problems in applying the PIC to a competitive environment. Even if one discounts the general considerations outlined above, there are specific problems with any application of the shift-and-rotation model. The best way to illustrate the problems is to consider an alternative hypothesis of the

behavior of a first source faced with the possibility of competition. This hypothesis states that in anticipation of competition, the first source increases its initial price and reduces the rate of price improvement during the period of sole-source purchases. By responding to the threat of competition in this manner, the first source increases the current flow of profits in response to the increased risk of lost revenues and profits due to the introduction of the second source.

The anticipation hypothesis is particularly important (and damaging to the standard methodology) because it has the same implications for the change in the parameters of the PIC as the shift and rotation hypothesis. Consequently, no empirical evaluation of competition based on the PIC formulation is able to distinguish between the shift and rotation hypothesis and the anticipation hypothesis. The conclusions on the effects of competition depend crucially on which hypothesis is correct. Acceptance of the shift-and-rotation hypothesis when the anticipation hypothesis is correct will result in overestimation of the benefits of competition.

The overestimation results from the fact that under the shift-and-rotation hypothesis the entire downward movement of the PIC is credited to competition. However, if the anticipation hypothesis is correct, the observed movement of the PIC should be decomposed into two parts. First, there would be an upward movement of the PIC as firms anticipated competition, and second, the increased costs associated with this response would be subtracted from the reduced costs observed when competition becomes effective.

Empirical Issues

The fundamental empirical problem with the PIC approach to competition analysis is that the learning curves tend to be highly unstable. The evidence on stability comes from work done by Alchian [22] during World War II but not released publicly until 1963. Alchian estimated learning curves for the production of military airframes using direct labor hours per pound of airframe as the independent variable.

The principal purpose of the research was to evaluate the learning curve as an analytical tool by examining the stability of the learning phenomenon. In this instance, stability was defined in terms of the ability of the model to predict the cumulative manhours required to produce the 1000th airframe, and the best model was defined as the one with the lowest mean absolute error of prediction. The best model had a mean absolute prediction error of 22 percent, with a range of error between -44 percent and +116 percent [22]. In addition, this best model used the initial program-specific data to define the learning curve.

Since price analysis has generally been done on a program-by-program basis, the results cited above have important implications for the degree of confidence that should accompany estimates of sole-source and competitive program costs. The instability of the underlying relationship is

compounded by the lack of consideration for the linkages between production inputs, costs, and prices. How much confidence should be placed in an estimate of 10 percent savings from competition when the baseline sole-source estimate is drawn from such an unstable environment? This evidence on the instability of the basic learning curve reinforces the view that the simple PIC-based analysis ignores too many factors to be of much use in evaluating the effects of competition on prices.

SUMMARY

The PIC approach to competition analysis has many shortcomings, the main one being the uncertainty about how competition affects the pricing behavior of firms before a competitor is introduced. The implicit, maintained hypothesis in the literature is that competition has no effect prior to its actual introduction. However, there are a number of ways in which this assumption can be violated--skimming and limit pricing are two examples.

Figure 8 illustrates this problem. The dashed lines in figure 8 represent two of the many alternative sole-source price improvement curves, while the solid lines represent the observed behavior of the original source. If the upper dashed line represents the PIC that would have been observed under purely sole-source conditions, then the observed prices under a competitive program would correspond to limit pricing by the original source. In this case, estimates of competitive savings based on the observed behavior would understate the effects of competition.

If the lower dashed line is representative of the sole-source PIC, then the observed behavior corresponds to skimming. As noted previously, the existence of skimming would result in overestimation of the benefits of competition based on observed prices.

In either case, the ambiguity about the position of the initial segment of the PIC is far from trivial. Estimated savings depend heavily on this initial position, and the theoretical uncertainty associated with the PIC compounds the statistical uncertainty of the small samples used in the literature.

In addition to the theoretical problems, there is the problem of the extreme variation in the estimated effects of competition on completed programs. This variation--which occurs across types of competition, within given types of competition, and across different studies of the same program--provides little guidance on where competition is most effective, and highlights the inadequacy of the PIC model as a tool for analyzing competition.

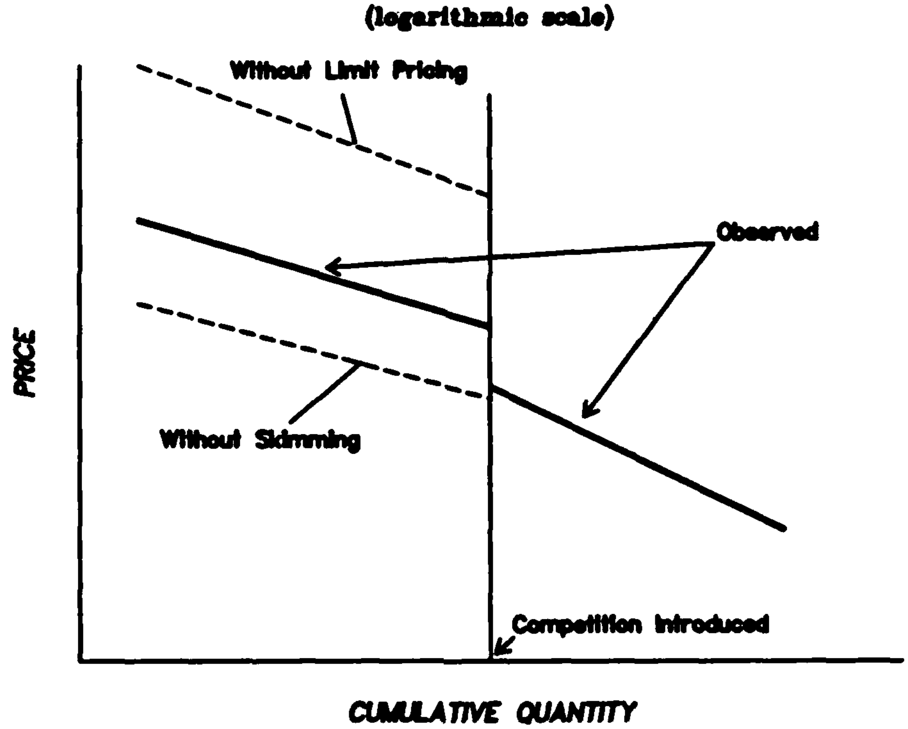

FIG. 8: OBSERVED AND HYPOTHETICAL PRICE IMPROVEMENT CURVES

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